

**Comparative Approaches to Superfund Site Assessments  
for Young Children Exposed to Lead**

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**TRANSPARENCIES FOR PRESENTATION**

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**THOSE PEOPLE, WHOSE BRAINS I'VE PICKED,  
SHOULD NOT BE BLAMED  
FOR ANY SINS OF OMISSION OR COMMISSION**

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## **BASIC ISSUES**

- \* Scale of assessment should match the scale of abatement or remediation**

**TARGET FOR ASSESSMENT:** Individual child or family

**SCALE FOR ASSESSMENT:** Individual house yards or lots

- \* Community assessment should be built up from small area (individual) assessments**
- \* Cross-sectional environmental studies and community blood lead studies may be useful insofar as they characterize existing conditions, but must be extrapolated cautiously when characterizing risk potential for future residents**
- \* There appear to be substantial differences among critical parameters at different sites**

## **BASIC APPROACHES**

- \* All approaches estimate geometric mean blood lead from environmental lead data**
  
- \* Risk is characterized by the probability that a child will exceed some specified blood lead level of concern (10, 15 or 20  $\mu\text{g}$  Pb per 100 ml whole blood), for a hypothetical population of children exposed to the specific household environment**
  
- \* Variability in blood lead in response to a specific environment is described by a lognormal distribution with a specified geometric standard deviation (GSD)**

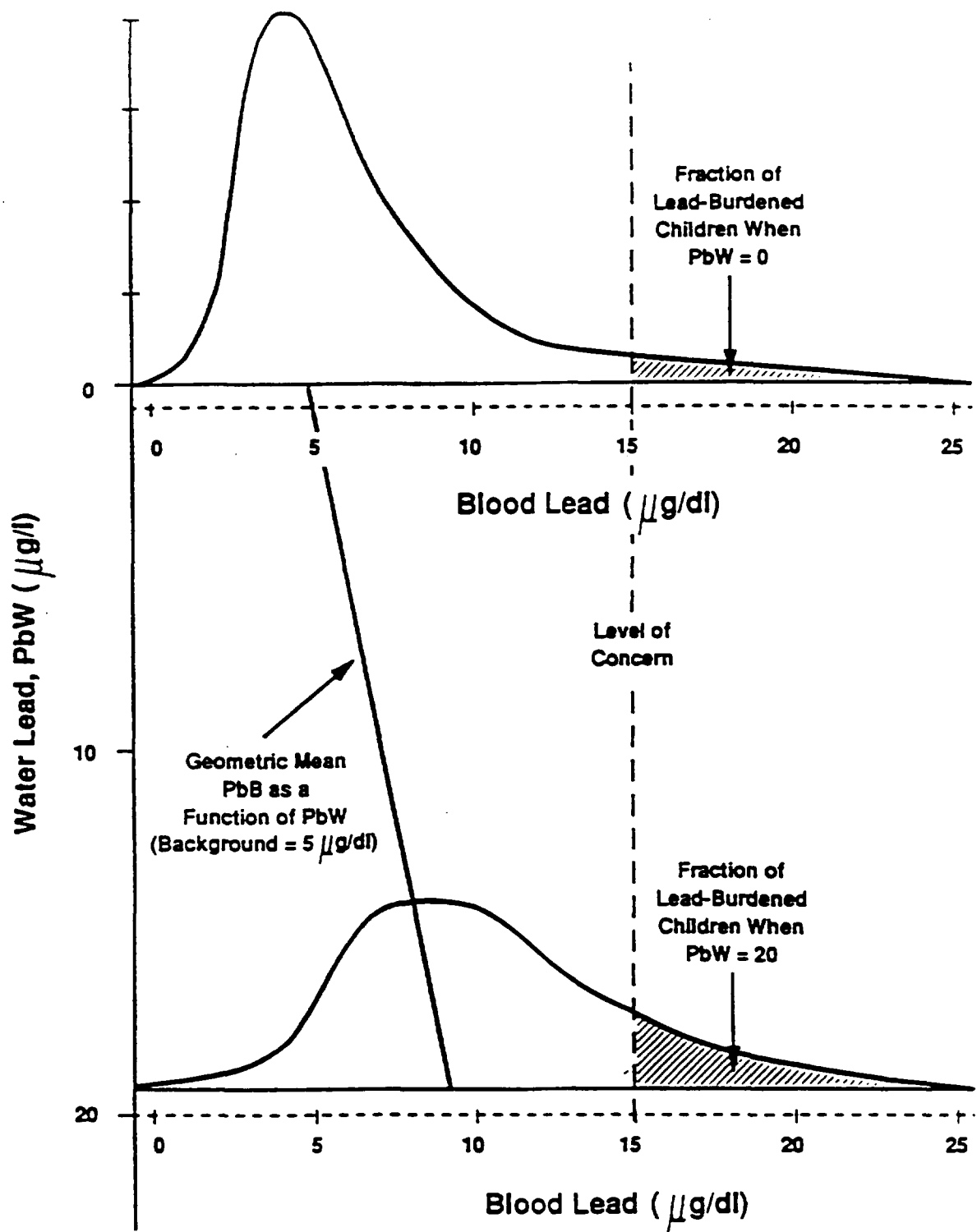
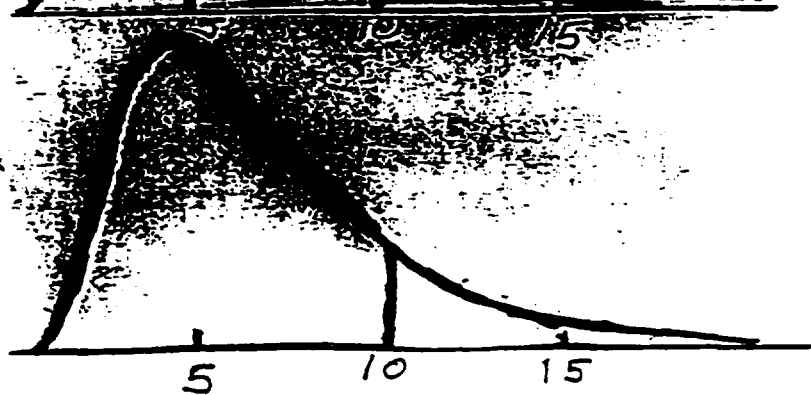
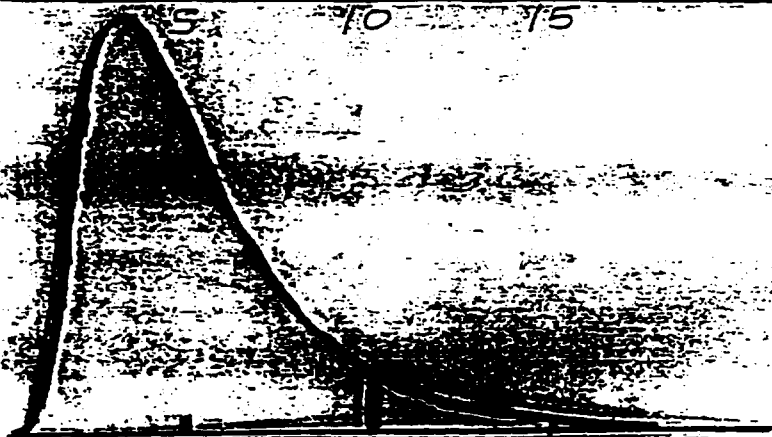
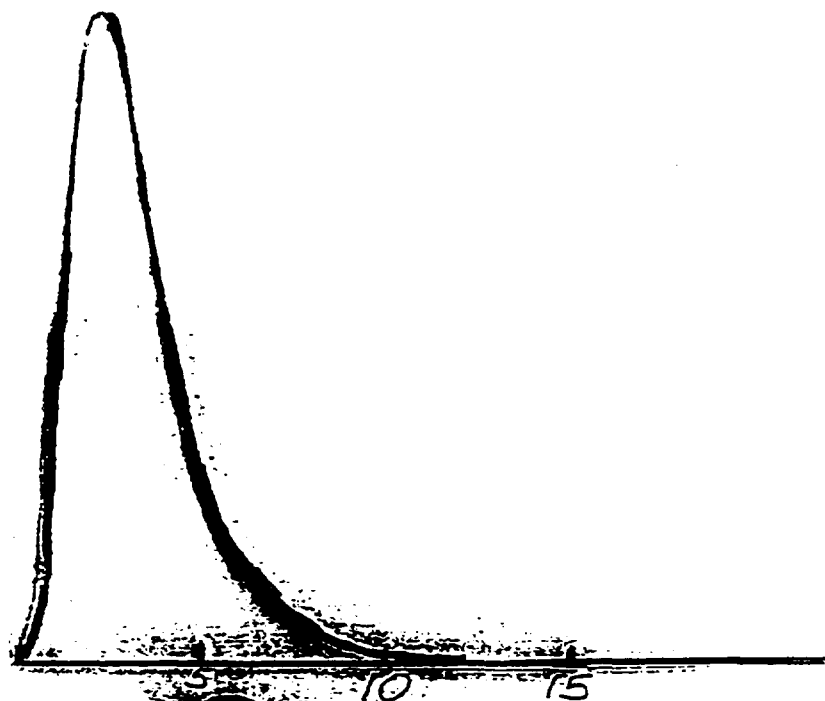
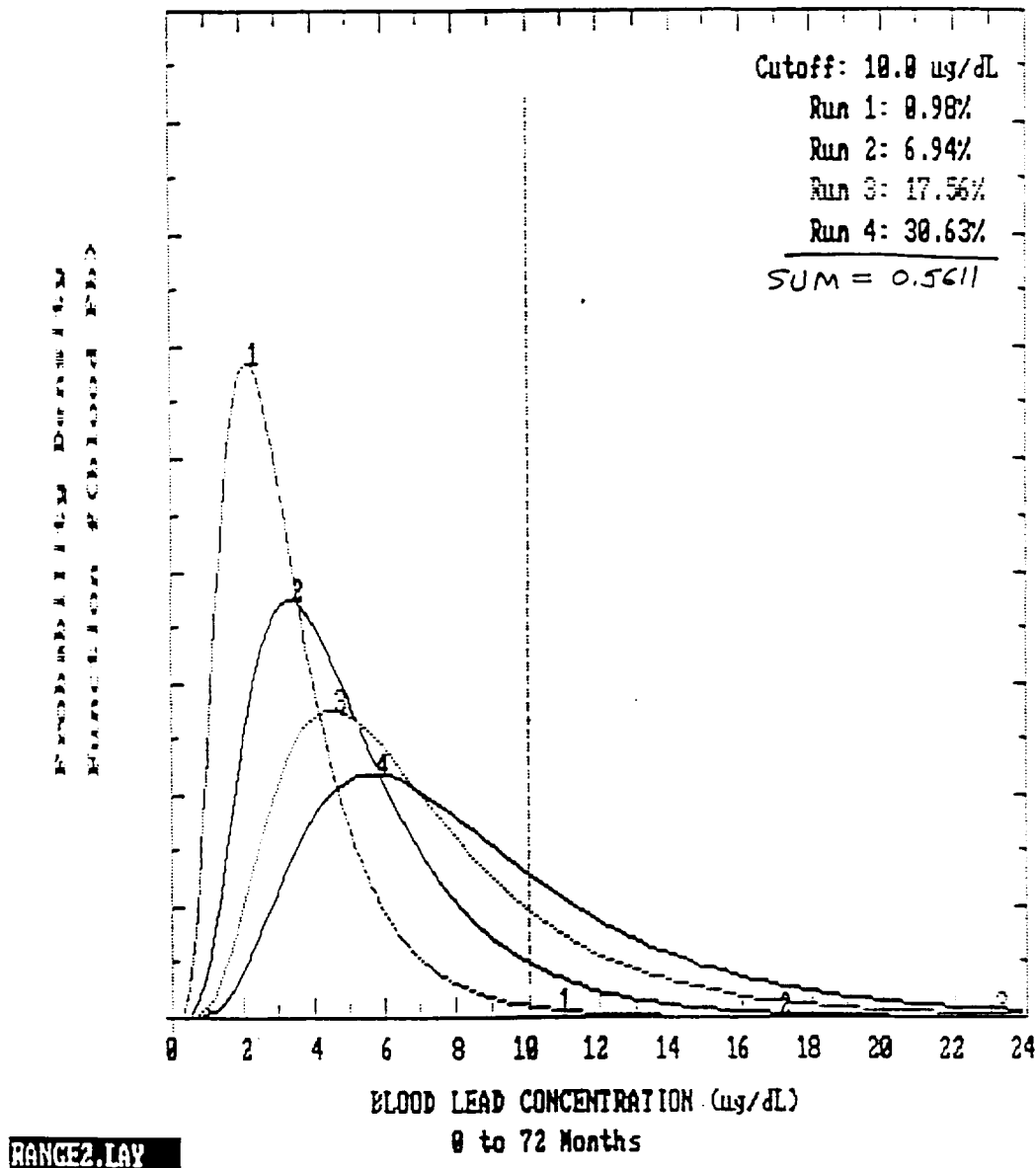


FIGURE 2. Distribution of Blood Leads at Different Water Lead Values



# Calculation of Individual Risk Using the Lead Model

$$\text{GSD} = 1.70$$



Blood Lead Distributions for Children Exposed to  
250, 500, 750, and 1000 ppm Lead in Soil Respectively.  
Blood Lead Estimated from Midvale Model Parameters.  
Total Risk is the Sum of the Four Individual Risks.

## **METHODS FOR ESTIMATING GEOMETRIC MEAN BLOOD LEAD**

- \* EPA Integrated Exposure Uptake and Biokinetic Model for Lead (UBK Model)**
- \* Non-linear or linear regression models for blood lead**
- \* Non-linear or linear systems of equations for blood lead and environmental lead exposure pathways**

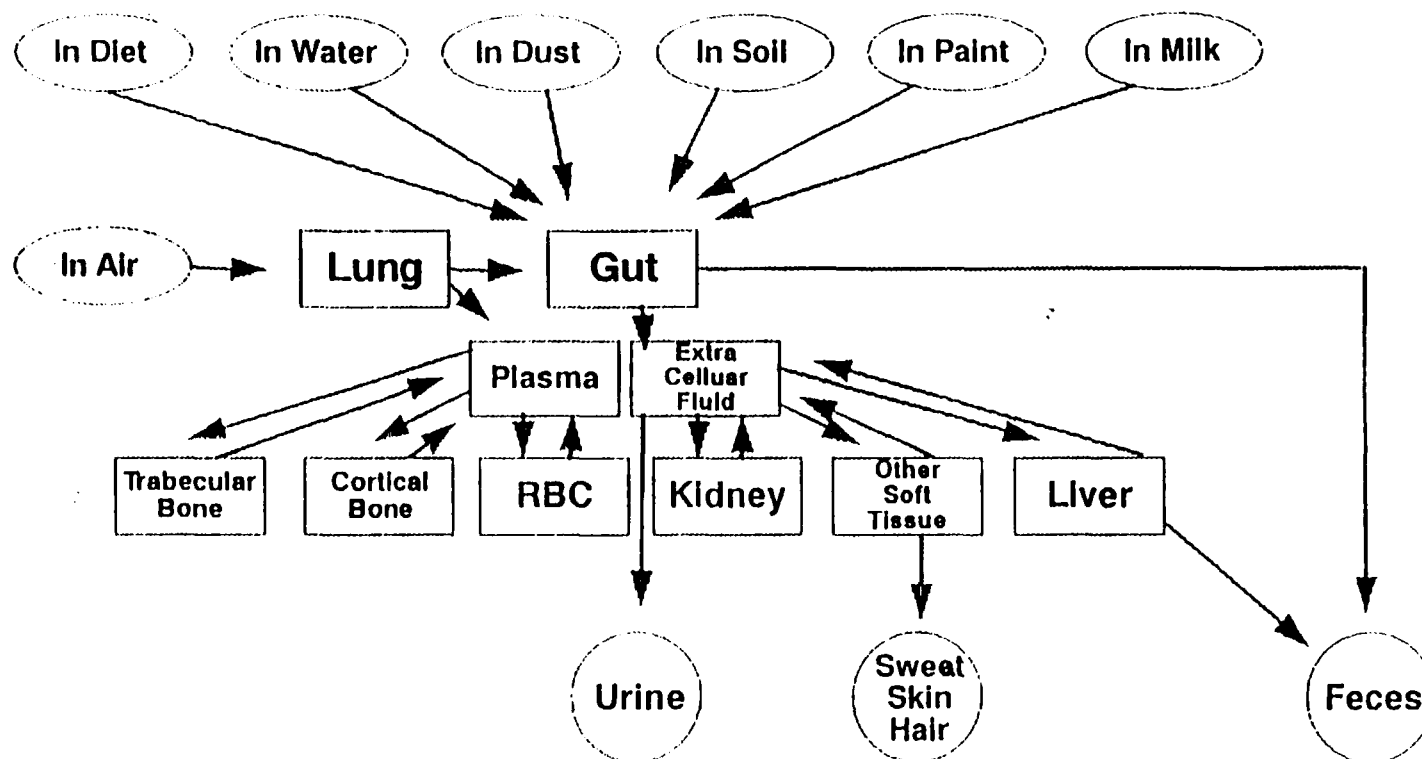


## **UBK MODEL FOR GM BLOOD LEAD**

- \* Compartmental biokinetic model with 8 physiological compartments**
- \* Normal growth of physiological pools or organs in fetus and child**
- \* Allometric scaling of biokinetics with body weight**
- \* Ingestion of food, and intake of environmental media such as air, water, soil, and dust, change with age**
- \* Linear and non-linear models for absorption of lead from different media**
- \* Partial validation - Needs work**

## THE MOST SENSITIVE PARAMETERS IN THE UBK MODEL

- (1) The bioavailability of lead in diverse media, particularly soil and household dust, and factors that affect bioavailability;
- (2) The strength of the pathway from lead in soil to lead in household dust, and the factors that affect childhood exposure;
- (3) The intrinsic variability in individual child response to exposure, and factors that affect inter-individual variability.



COMPARTMENTAL MODEL FOR BIOKINETIC COMPONENT OF LEAD COHORT MODEL. OVAL BLOCKS REPRESENT LEAD SOURCES. CIRCLES REPRESENT ROUTES FOR ELIMINATION OF LEAD FROM THE BODY. RECTANGULAR BLOCKS REPRESENT COMPARTMENTS OF THE BODY OF THE CHILD. PENTAGONAL BLOCKS REPRESENT DOSE-DEPENDENT OR NONLINEAR BIOKINETIC PROCESSES.

## **REGRESSION MODELS FOR GM BLOOD LEAD**

### **PHYSICALLY AND BIOLOGICALLY REALISTIC MODELS USING ADDITIVITY OF LEAD FROM DIFFERENT SOURCES**

1. **Log transformation of linear model in environmental lead**
2. **Log transformation of nonlinear model approximating the  
UBK model**

### **CONVENIENT BUT UNREALISTIC MODEL IN WHICH DIFFERENT LEAD SOURCES ARE MULTIPLICATIVE**

3. **Linear model in logarithm of environmental lead**

## Structural equation model fitted to full sample Midvale data.

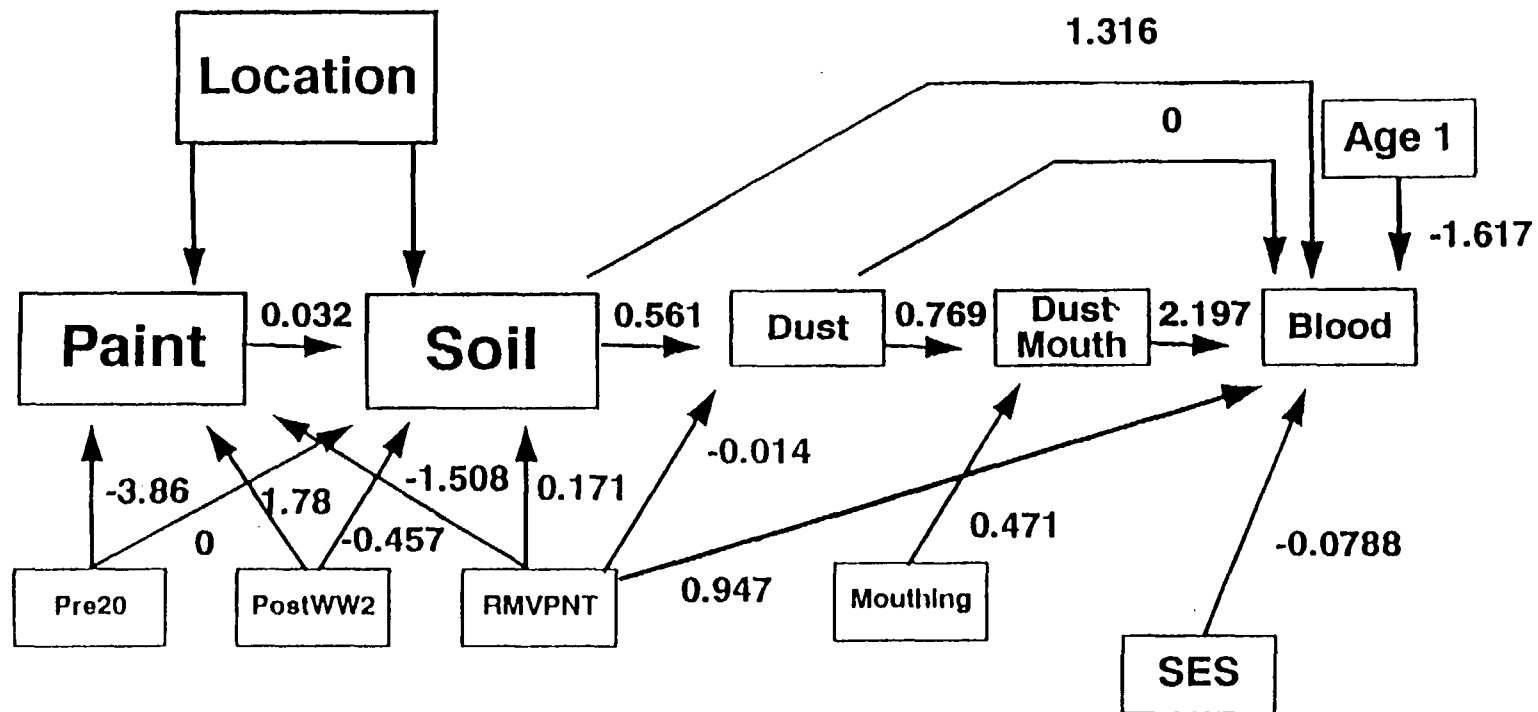


FIGURE 5-3. Structural equation model from data in Bornschein et al. (1990) and Marcus (1991).

## MATHEMATICAL MODELS FOR BLOOD LEAD VS. ENVIRONMENTAL LEAD PHYSICALLY AND BIOLOGICALLY REALISTIC MODELS

### 1. LOG-TRANSFORMED LINEAR TOTAL LEAD EXPOSURE MODEL

$$\text{LOG(PbB)} = \text{LOG}(B_0 + B_W \text{PbW} + B_S \text{PbS} + B_D \text{PbD} + \dots)$$

### 2. LOG-TRANSFORMED TOTAL LEAD EXPOSURE MODEL WITH PARTIALLY SATURABLE ABSORPTION OF TOTAL INGESTED LEAD INTAKE

(this approximates the UBK non-linear absorption model with near-constant lead exposure except for normal age-related changes)

$$\begin{aligned} \text{LOG(PbB)} = & \text{LOG}(B_0 + B_W \text{PbW} + B_S \text{PbS} + B_D \text{PbD} + \\ & (K_0 + K_W \text{PbW} + K_S \text{PbS} + K_D \text{PbD}) / \\ & (1 + (I_0 + Q_W \text{PbW} + Q_S \text{PbS} + Q_D \text{PbD}) / I_{\text{Pbsat}})) \end{aligned}$$

The amount of water, soil, dust ingested per day, denoted  $Q$ , is assumed to be known. Intake parameters are denoted  $I$ .

MATHEMATICAL MODELS FOR BLOOD LEAD VS.  
ENVIRONMENTAL LEAD  
PHYSICALLY AND BIOLOGICALLY REALISTIC MODELS

3. LOG-TRANSFORMED TOTAL LEAD EXPOSURE MODEL WITH PARTIALLY SATURABLE ABSORPTION ESTIMATED USING UBK MODEL PARAMETERS.

$$\begin{aligned} \text{LOG(PbB)} = & -\text{LOG}(\text{Biokinetic Lead Clearance Rate}) + \\ & \text{LOG}[\text{AbsP}_{\text{diet}} \text{IPb}_{\text{diet}} + \text{AbsP}_W Q_W \text{PbW} + \text{AbsP}_S Q_S \text{PbS} + \\ & \text{AbsP}_D Q_D \text{PbD} + \text{Abs}_A Q_A \text{PbA} + \\ & (\text{AbsA}_{\text{diet}} \text{IPb}_{\text{diet}} + \text{AbsA}_W Q_W \text{PbW} + \text{AbsA}_S Q_S \text{PbS} + \\ & \text{AbsA}_D Q_D \text{PbD}) / \{1 + (\text{IPb}_{\text{diet}} + Q_W \text{PbW} + Q_S \text{PbS} + \\ & Q_D \text{PbD}) / \text{IPb}_{\text{sat}} \}] \end{aligned}$$

PHYSICALLY AND BIOLOGICALLY UNREALISTIC  
(but convenient) MODELS

4. LINEAR MODEL IN LOGARITHM OF ENVIRONMENTAL LEAD

$$\text{LOG(PbB)} = \text{LOG}(B_0) + B_W^{\text{log}} \text{PbW} + B_S^{\text{log}} \text{PbS} + B_D^{\text{log}} \text{PbD} + \dots$$

COMPARISON OF STRUCTURAL EQUATION MODEL  
ESTIMATES OF BLOOD LEAD VS. SOIL AND DUST LEAD  
REGRESSION COEFFICIENT

STUDY	TYPE	BLOOD LEAD COEFFICIENT ( $\pm$ s.e.) ( $\mu\text{g}/\text{dl}$ PbB per $\mu\text{g}/\text{g}$ )	
		Soil Lead	Dust Lead
E. Helena 1983	Active Smelter	2.24 (0.79)	1.54 (0.51)
Kellogg 1983	Unused Smelter	0.34 (0.16)	2.14 (0.85)
Midvale 1989	Mixed	3.05 (0.89)	1.55 (0.58)
Butte 1990	Mining\Smelter	0.00 (0.12)	1.99 (0.59)



COMPARISON OF STRUCTURAL EQUATION MODEL  
ESTIMATES OF DUST LEAD VS SOIL LEAD  
REGRESSION COEFFICIENT

STUDY	DUST LEAD COEFFICIENT ( $\pm$ s.e.) ( $\mu\text{g/g}$ PbD per $\mu\text{g/g}$ PbS)
E. Helena - 1983	0.928 (0.127)
Kellogg - 1983	0.100 (0.046)
Midvale - 1989	0.756 (0.077)
Butte - 1990	0.266 (0.040)

# **INDIVIDUAL VARIABILITY IN THE USEPA LEAD MODEL**

**MODEL PREDICTS GEOMETRIC MEAN BLOOD LEAD**

**SOURCES OF VARIABILITY:**

- **INDIVIDUAL BIOKINETIC PARAMETERS**
- **INDIVIDUAL DIFFERENCES IN AMOUNT OF MEDIA INTAKE**
- **INDIVIDUAL DIFFERENCES IN ABSORPTION/BIOAVAILABILITY**
- **INADEQUATE CHARACTERIZATION OF EXPOSURE BY MEASURED ENVIRONMENTAL LEAD CONCENTRATIONS**
- **REPRESENTATION OF INDIVIDUAL EXPOSURE BY COMMUNITY AVERAGE**

**VARIABILITY IS INCLUDED BY ASSUMING A LOGNORMAL DISTRIBUTION OF BLOOD LEAD WITH GIVEN GEOMETRIC MEAN**

**SPECIFICATION OF THE GEOMETRIC STANDARD DEVIATION OF BLOOD LEAD IS A SENSITIVE PARAMETER IN RISK ASSESSMENT**

**NOT COMPUTATIONALLY FEASIBLE TO ASSUME A DISTRIBUTION FOR EACH INPUT PARAMETER**

## EMPIRICAL ESTIMATION OF BLOOD LEAD GSD

- \* THE LOGARITHM OF THE GSD IS THE STANDARD DEVIATION OF THE RESIDUAL DEVIATIONS BETWEEN OBSERVED AND PREDICTED LOGARITHM OF BLOOD LEAD LEVELS IN A POPULATION
  
- \* RESIDUAL GSD FROM PREDICTED BLOOD LEAD:
  - NON-LINEAR OR LINEAR REGRESSION MODELS
  - NON-LINEAR OR LINEAR STRUCTURAL EQUATION MODELS
  - EMPIRICALLY CALIBRATED UBK MODEL WITH NO BIAS IN GEOM. MEAN
  
- \* THE GSD MAY BE ESTIMATED BY WITHIN-FAMILY VARIABILITY IN LOG BLOOD LEAD IN HOUSEHOLDS WITH 2 OR MORE PRE-SCHOOL CHILDREN, ADJUSTED FOR INDIVIDUAL CHILD AGES AND OTHER DIFFERENCES.
  - POOLED VARIANCE ESTIMATE
  - NESTED ANALYSIS OF COVARIANCE
  
- \* ALL METHODS APPLIED TO DATA FROM BUTTE AND MIDVALE HAVE INDIVIDUAL CHILD GSD OF 1.65 OR LARGER

TABLE .      Nested Analysis of Variance for Family Size Effect  
on Blood Lead GSD in 166 MIDVALE Children in Families  
with 1 to 3 Children Less Than 7 Years of Age

**ADJUSTED FOR AGE CLASS AND MOUTHING, SOCIOECONOMIC STATUS**

EFFECT	SS	df	MS	P	R <sup>2</sup>	GSD
Age Class	2.9155	5	0.5831	0.1594		
Mouthing	1.5740	1	1.5740	0.0385		
SES	7.8524	1	7.8524	< 10 <sup>-6</sup>		
Family	10.2547	38	0.2699	0.8441		
Error	42.7779	119	0.359479		0.355	1.821

**ADJUSTED FOR AGE CLASS, MOUTHING, SOCIOECONOMIC STATUS,  
SOIL AND DUST LEAD\***

EFFECT	SS	df	MS	P	R <sup>2</sup>	GSD
Age Class	3.7353	5	0.7471	0.0506		
Mouthing	1.9745	1	1.9745	0.0154		
SES	7.6269	1	7.6269	4.10 <sup>-6</sup>		
Log Dust Lead	0.1378	1	0.1378	0.5175		
Log Soil Lead	2.4092	1	2.4092	0.0076		
Family	10.5121	36	0.2920	0.8935		
Error	37.9100	116	0.326810		0.423	1.771

## **PARAMETERS FOR POST-REMEDIATION ASSESSMENT**

- \* Remediation may grind course particles or soils into fine particles that are more readily transported into the house and are more bioavailable**
- \***
- \* Normal weathering may cause some surface material to become more aggregated and others more fractionated**
- \* Normal human activities such as gardening and housing construction may grind coarse particles and soils into fine particles**

## **DIFFERENCES AMONG SITES**

### **\* BIOAVAILABILITY**

**Fine particles - higher bioavailability**

**Coarse particles or aggregated soils - lower bioavailability**

**Insoluble chemical species often less bioavailable, may be highly bioavailable if fine particles**

### **\* EXPOSURE PATHWAYS**

**Extremely wide range from low to high ratio of dust lead to soil lead concentration. May depend on particle size.**

## SUMMARY AND CONCLUSIONS

- \* ESTIMATES OF RISK OF ELEVATED BLOOD LEAD FOR CHILDREN IN A COMMUNITY CAN ALWAYS BE AGGREGATED FROM THE SUM OF INDIVIDUAL RISKS AT HOUSEHOLDS WITHIN A COMMUNITY, REQUIRING ONLY ENVIRONMENTAL SAMPLES OF SOIL, DUST, AIR AND WATER AT A REPRESENTATIVE SAMPLE OF HOUSES OR POTENTIAL RESIDENTIAL SITES
- \* IT IS NOT NECESSARY TO ASSUME COMMUNITY ENVIRONMENTAL LEAD DISTRIBUTIONS TO EVALUATE POST-REMEDATION EXPOSURE SCENARIOS AND TO DETERMINE TRIGGER LEVELS FOR SOIL/DUST LEAD REMEDIATION USING THE SUM OF INDIVIDUAL HOUSEHOLD RISKS
- \* RISKS OF ELEVATED BLOOD LEAD IN YOUNG CHILDREN EXPOSED TO LEAD-CONTAMINATED RESIDENTIAL SOIL CAN BE ASSESSED BY SEVERAL METHODS, WITH THE UBK MODEL OFFERING GREATER FLEXIBILITY IN DEALING WITH INTER-SITE DIFFERENCES IN CRITICAL PARAMETERS:
  - IMPORTANCE OF SOIL-TO-DUST PATHWAY
  - BIOAVAILABILITY OF LEAD IN SOIL, INCLUDING NON-LINEARITY
  - INTER-INDIVIDUAL DIFFERENCES IN BLOOD LEAD RESPONSE TO ENVIRONMENTAL LEAD EXPOSURE
- \* DUST LEAD APPEARS TO BE HIGHLY BIOAVAILABLE AT ALMOST ALL SITES; SOIL LEAD BIOAVAILABILITY VARIES GREATLY AMONG SITES AND IS LIKELY TO DEPEND ON PHYSICAL AND CHEMICAL PROPERTIES OF LEAD-BEARING SOIL MATERIALS
- \* IMPORTANCE OF THE SOIL-TO-DUST PATHWAY VARIES GREATLY AMONG SITES AND MAY DEPEND ON PHYSICAL AND CHEMICAL PROPERTIES OF LEAD-BEARING SOIL MATERIALS
- \* INTER-INDIVIDUAL VARIABILITY, MEASURED BY THE BLOOD LEAD GSD, IS RELATIVELY HIGH EVEN WITHIN FAMILIES EXPOSED TO THE SAME ENVIRONMENTAL LEVELS OF A LEAD. A GSD OF 1.65 OR LARGER MAY BE NEEDED AT MOST LEAD MINING AND SMELTER SITES.
- \* REMEDIATION MAY CHANGE SENSITIVE PARAMETERS